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Statistical analysis of heavy rainfall over two tropical stations in India

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Abstract : Rain is the most important parameter which affects the microwave and millimetre wave communication links and radar propagation In this paper, the rain rate distribution, duration of rain rate, number of exceedances of different thresholds, probability of exceedances with respect to total rainfall time and outage probability have been studied over Calcutta and Delhi. Such results are useful to estimate the performance of communication links and radar propagation in relation to rain attenuation, fade margin, fade duration etc. The cumulative rain rate distribution during all months over Calcutta and Delhi for the period 1985-88 are also examined The degree of variablity of duration and the number of exceedances for different rain rate thresholds are also shown. The number of exceedances as well as duration of different rain rates are found to be greater over Calcutta where heavy rainfall occurs as compared to those over Delhi, where rainfall is relatively less

Keywords : Rain fall, exceedances, tropical stations

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1. Introduction

Rain causes serious degradation in microwave and millimetre wave propagation. The signal attenuation produced by rain on radio communication in these frequency bands become higher as frequency increases. This is mainly because the rain drops are lossy dielectrics having large dielectric constant due to which heavy displacement current flows inside each rain drop. As a result, the ohmic losses in the rain drops at the frequency of operation produces sizeable signal attenuation [1–4]. Besides the ohmic loss, scattering in the raindrops may also introduce some additional attenuations of the signal. The attenuation in raindrops is more as compared to that produced by other hydrometeors like hail, ice, fog, cloud and snow. The rain rate measurements by using rain gauges having integration time 10 sec over different stations in India were made by the NPL group [5] and derived results on probability distribution. Such results are utilised along with the rain fall data reported by the India Meteorological Department to develop model to estimate rain rate distributions [6]. The detail statistical results presented in this paper is due to the availability of very systematic rain fall data provided by the IMD. The results presented here can be transformed in the results which are achieveable with rainfall data taken by rain gauges with integration time 10 sec. Such results are useful to users of microwave and millimeter wave communication. A good number of models on drops size distribution have been employed for evaluation of the effect of millimetre and microwave propagation due to rainfall. Models of Laws and Parsons [7], Marshall and Palmer [8], *etc.*, on drop size are widely used for the estimation of rain attenuation. But modelling studies on dropsize distribution for microwave and millimetre wave, following the above two models [7,8] have been shown to be inadequate for tropical station Ile-Ife in south western Nigeria [9]. It is observed that frequency bands less than 10 GHz are getting congested, particularly, in the developed countries since quite some time back. Therefore, a need for going to higher frequencies was felt; and the World Administration Conference (WACR) held in Geneva in 1979, allowed the developed and developing countries to share the higher frequencies, so that these countries can plan their communication networks using wide band microwave systems. But the main hurdle for using the higher frequencies is the rainfall. It is the serious source of attenuation of microwave communication for frequencies higher than 10 GHz. The microwaves with frequencies less than 10 GHz have wavelength much larger than the rain drop size and thus are not affected much by rains. On the otherhand, as the frequency increases, the wavelength approaches the dimension of dropsize. The rain drops, apart from its producing displacement current due to its higher dielectric constant, then acts as a screen for the incident wave and affect the transmission quality, limiting the performance of the system. The system performance gets degraded more in the region where rainfall is more. Therefore, rain rate statistics over an area are very much necessary for a system design. The percentage times during which absorption are significant are estimated from this rain statistics and thereby the rain induced outage time. Moupfouma [10,11] has provided an extensive account of rainfall statistics, its types, variability and parametrizations considering a wide range of rain zone of the globe, and developed models of rainfall rate distribution for radio system designing. Information about the time variant fading is very important for microwave communication. Therefore, fade dynamics, duration of fade *etc* are the subjects which are recently being looked closely world-wide. Naturally, it relates to the subjects of rainfall rate. The duration of exceedances of different rain rates (thresholds) has, of late, become the topic of studies [12,13]. The detailed accounts of rainfall rate and duration statistics for microwave system design have been provided by Villar *et al* [14], Burgueno [15] and Lin [16]. From all these studies, it is now clear that not only the magnitude and probability of occurrence of fades are important, but their durations are also important for microwave and millimetre wave communications. This can be put in a simpler way that if we know the average duration of a fading, then a decision can be made to take action or wait for the signal to recover. Thus, the rain attenuation can be better estimated if the rain chracteristics such as rain rate, duration, dropsize, extension of rain cells (equivalent path lengths) *etc.* are known.

Based on the above considerations, a detailed study has been made on the rain rate, exceedances with respect to total rainfall time in an average year and the outage probability per year for Calcutta (22°9 N, 88°27 E) and Delhi (28°32 N, 77°12 E) considering rain data for the years 1985-88. The results are analysed and presented in this paper.

2. Source of data

The rain data were collected from the India Meteorological Department (IMD). The rain gauges used by IMD are the tipping bucket type, developed on the specifications prescribed by the World Meteorological Organization (WMO). The heavy rainfall analysis data derived from such rain gauges are utilised in this study. The tipping bucket type rain gauges are being used over a large number of meteorological stations including Calcutta and Delhi in India The recording of rain rates indicated many features which are described in the present study.

3. Distribution of rain rate

The rain data considered in this study are pertaining to the period 1985-88 for Delhi and 1985-87 for Calcutta. The year wise cumulative distribution of rain rate for Calcutta and Delhi are shown in Figures 1 and 2 respectively. It is observed from Figure 1 that over the

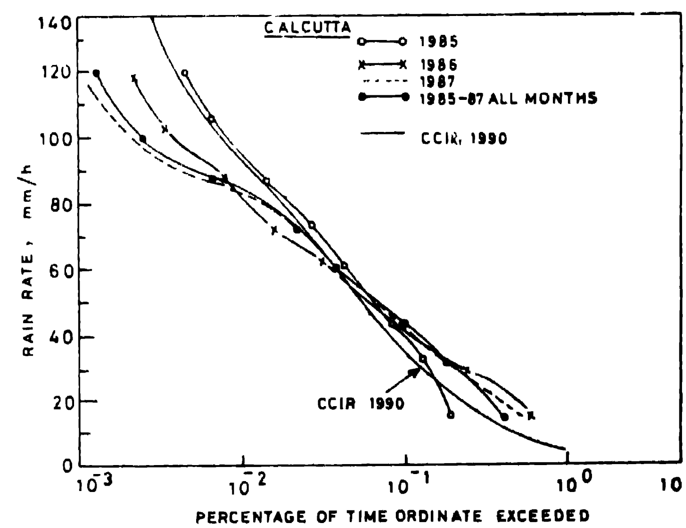

Figure 1. Year-wise cumulative distribution of rain rate for Calcutta

coastal station Calcutta, the year-to-year variations in rain rate distribution are not substantial. The CCIR (1990) values presented in Figure 1 also shows a good agreement to the measured values. But in case of Delhi (Figure 2), the year-to-year variability in rain rate is quite substantial. The curves obtained from CCIR (1990) values are also presented.

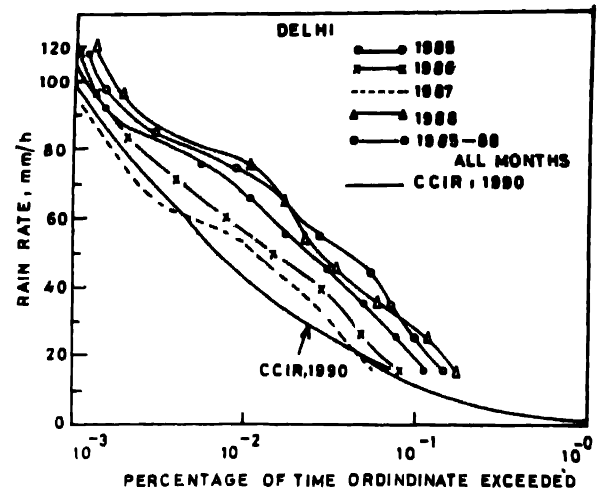

Figure 2. Year-wise cumulative distribution of rain rate for Delhi

According to the CCIR (1990) classification, Delhi comes under the *K*-type rain climate. The difference between the CCIR values and the year-to-year measured values over Delhi are also found to be substantial. Thus from Figures 1 and 2, it is found that the CCIR values correspond more closely with the values observed over Calcutta rather than those over Delhi.

The average distributions for all these years considering all months are also shown in Figures 1 and 2. A comparision also shows that the average rain rate over Calcutta at 10^{-2}% probability level is 85 mm/h, whereas that over Delhi is 65 mm/h at the same probability level.

Table 1. Worst month rainfall and its rate over Calcutta and Delhi

Place and month		Average rainfall mm	Rain rate (including non-rainy days) mm/h
Calcutta	June	156 6	0.217
	July	333.5	0.463
	August	183.1	0.254
	Sept	242.0	0.336
Delhi	July	144.3	0.200
	August	139.3	0.194

In support of this result, it may be mentioned that a systematic measurements of both rain rate using fast response rain-gauge and microwave propagation around 13 GHz for LOS terrestrial as well as slant paths, were made by Calla *et al* [17], over six climatic regions in India and their results indicated that the Indian Subcontinent may be subdivided into nine distinct rain regions instead of only one, as indicated by the CCIR. The worst months are defined as those months in which maximum total rainfall as well as 30% of the maximum is observed. Table 1 shows the total rainfall and its rates for different worst months over Calcutta and Delhi. The total rainfall in a particular month has been taken as the average of 4 and 3 years total rainfall in that particular month over Delhi and Calcutta respectively.

4. Duration of rain rate and its analysis

The present study focuses on the statistics of rain rate (R in mm/h) and duration (D) of exceedance of a particular rain rate. The analysis of rainfall rate is necessary for the microwave and millimetre wave propagation. The parameters R, D and T_1, [where T_1 represents total time of propagation experiment in hrs (or min)] are required for the analysis of rain rate data. The total time/duration (D) of exceedance of a particular rain rate (R) may then be represented as the percentage (P) of total time (T) of records, *i.e.* $P = D \times 100/T_1$. Therefore as pointed out by Villar *et al* [14] and others [11], the study of duration of exceedance of different rain rate is as important as that of magnitude and probability of occurrence of fade for the propagation studies. Moreover, the duration of precipitation rate, particularly of high intensity, is of immense importance for estimating the fade out period and, consequently, for taking corrective measures for microwave communication system. The present analysis is based on the rain data provided by the IMD. Here, a continuous record of rain has been called as an event.

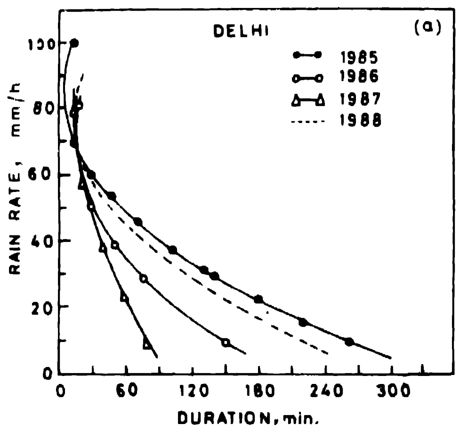

Figure 3. Year-to-year variation of duration of different rain rates over (a) Delhi

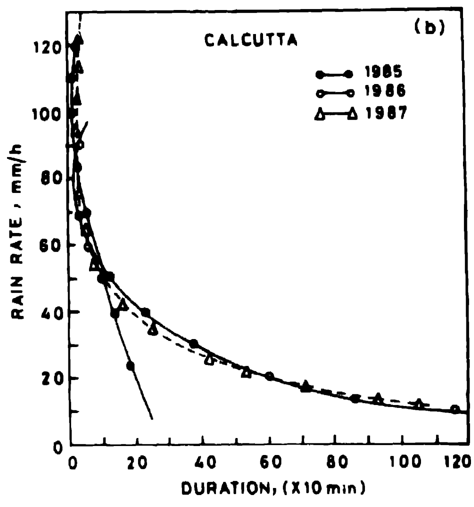

Figure 3. Year-to-year variation of duration of different rain rates over (b) Calcutta

Rain events of 2 min and above are considered for calculating total rainfall time over Delhi, while over Calcutta, events of 15 min and above are taken into consideration for calculation of total rainfall time. Different rain rates and their respective duration are calculated from the rainfall data obtained from the IMD having an integration time ~ 15 min. Figures 3(a) and 3(b) show the year-to-year variations of durations of different rain rates over Delhi and Calcutta respectively The duration of any particular rain rate is found to be more over Calcutta than over Delhi. The duration of rain rate is found to vary substantially from year-to-year over Delhi, while, over Calcutta, except for the rates less than 40 mm/h in the year 1985, the duration of any rain rate remained almost the same. As one proceeds towards higher rain intensity (50 mm/h and above), the year-wise variation of rain rate duration becomes insignificant over both Delhi and Calcutta, though the rain rate over Calcutta continues for longer time than that over Delhi. Figures 4(a) and 4(b) show the

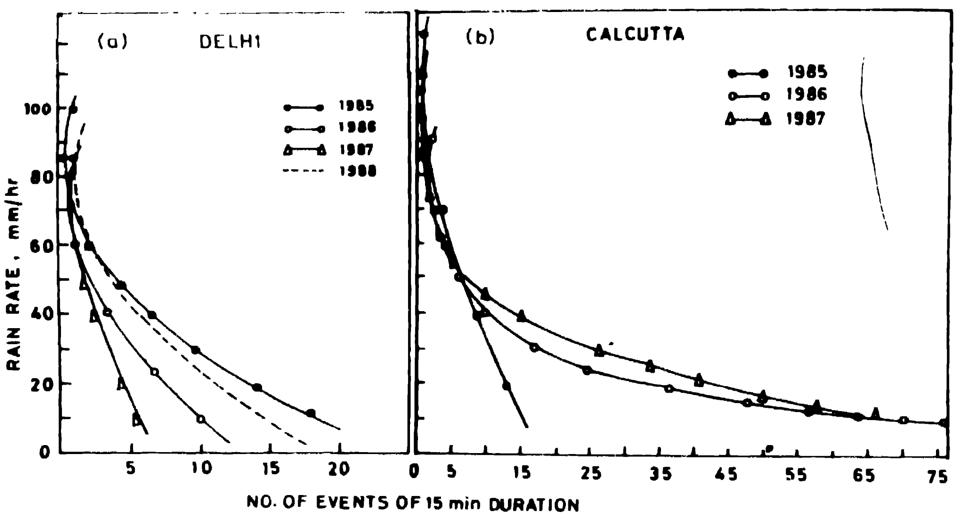

Figure 4. Year-to-year variation of no of events of 15 min duration with respect to rain rate over (a) Delhi and (b) Calcutta

year-wise variation of number of events of 15 min duration with respect to rain rate over Delhi and Calcutta, respectively. For Delhi, wide variability in the number of event is observed for different rain rates as one moves from one year to another. On the other hand, over Calcutta, there is almost no variation for the years 1986 and 1987, but a substantial deviation is observed for the year 1985 towards the lower rate of precipitation. Again, the number of events is found to decrease exponentially for higher rain rates for both the stations. From Figures 4 [(a) and (b)] it can be inferred that the year-wise variability of the events is more, over Delhi

5. Exceedances and thresholds of rainfall

The statistical analysis of duration, D and intensity, R of rain exceedances relevant to the designing of microwave communication systems has been discussed here.

When a rain rate exceeds a particular value, it is called an exceedance The particular value of rain rate that is exceeded is then known as threshold. Each exceedance has an associated duration (D). In the present study, we wanted to have well discriminated durations and thresholds. Here, only 12 thresholds are used covering the rain rate from 10 mm/h to 120 mm/h. It may be mentioned here that rain events of 15 min duration and above are only considered (though for the calculation of total rain fall time events of 2 min and above are taken for Delhi, and events of 15 min and above are considered for Calcutta).

Figure 5 [(a)–(d)] shows the number of exceedances on a per-year basis as a function of the threshold being equalled or exceeded In Figure 5(d), only the Delhi values are shown

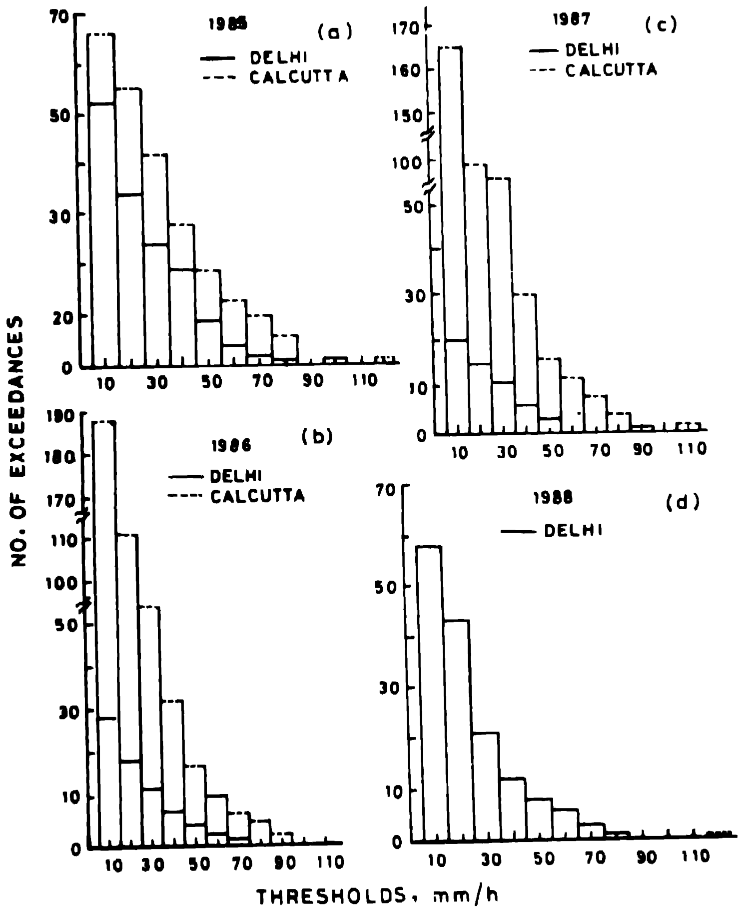

Figure 5. Histograms showing the no of exceedances as a function of threshold being equalled or exceeded over Calcutta and Delhi for the year (a) 1985, (b) 1986, (c) 1987 and (d) 1988 (over Delhi only)

for 1988. The histrograms represent the cumulative statistics of exceedance numbers. The exceedance numbers that exceed lower thresholds are always found to be greater for every year. The number is much higher over Calcutta at any threshold level in every year as compared to Delhi, though a comparatively lower number of exceedances are recorded for the year 1985. The average number of time $(\bar{N})$ per year (cumulative) that an indicated rainfall rate exceedance lasts for 15 min are presented in Table 2. The corresponding durations (D) as well as the average time of total rainfall per year $(\bar{D})$ are also shown in Table 2.

Table 2 Average number of time $(\bar{N})$ per year that a particular rain rate exceedance continues for 15 min

Av no of exceedance $(\bar{N})$ and duration (D)	Rain rate (threshold) in mm/h exceeded											
	10	20	30	40	50	60	70	80	90	100	110	120
	For Delhi											
$\bar{N}$	39.5	27.5	17.25	11	6	3	1.5	0.5		0.25		
$D_{(min)}$	592.5	412.5	258.75	165	90	45	22.5	7.5		3.75		
	For Calcutta											
$\bar{N}$	140	80	51	30	18	12	8	5	0.66		0.66	0.3
$D_{(min)}$	2095	1325	760	452	265	180	125	75	10	-	10	5

Note. Average time of total rain fall per year $(\bar{D})$ = 2251 min for Calcutta and 829.75 min for Delhi

Figure 6 shows the probability of exceedance of threshold during total rainfall time as a function of threshold. This probability of exceedance may be termed as the fractional

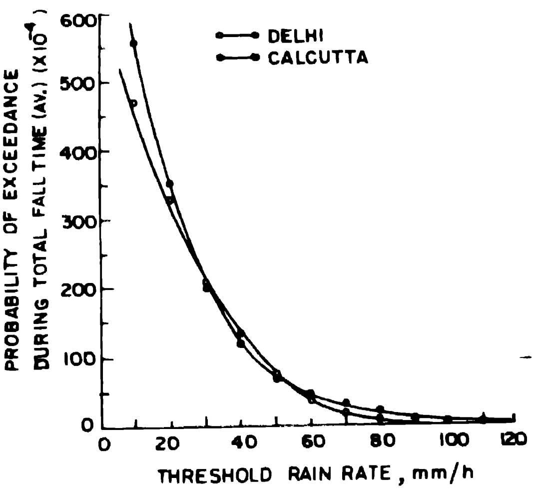

Figure 6. Probability of exceedance of threshold as a fucntion of threshold.

number of exceedances (P_n) with respect to total time of rainfall per year and is defined as the ratio of the number of exceedances and the total rainfall time per year, *i.e*:

$$P_n = \overline{N} / \overline{D}$$

where, $\overline{N}$ = Average number of times per year that a particular threshold is exceeded

$\overline{D}$ = Average total rainfall time per year

As far as the probabilities are concerned there is no substantial deviation between Calcutta and Delhi. This is due to the fact that over Calcutta where the rain time in a year is more, the corresponding number of exceedances are more. But in Delhi, as the rain time per year is less, the corresponding exceedance numbers are also less. Therefore, the $\overline{N} / \overline{D}$ values over Calcutta and Delhi at the same thresholds do not show any deviation. The exponential nature of the probability curve shows that the exceedance probability is higher at lower values of thresholds. Figure 7 shows the probability of duration of exceedance (P_d) as a

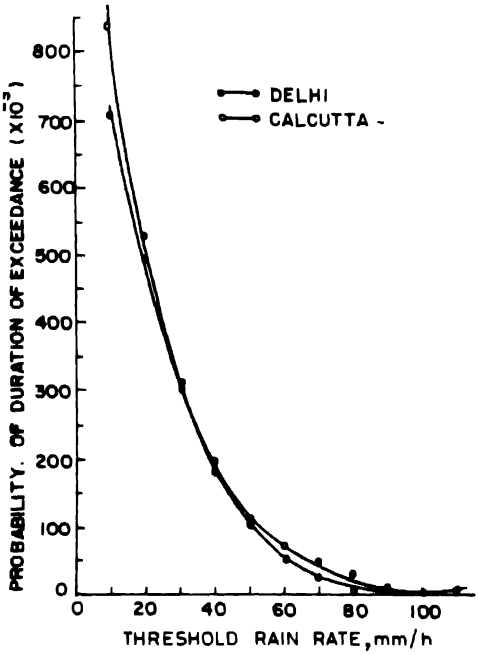

Figure 7. Probability of duration of exceedances as a function of threshold

function of thresholds. The parameter P_d is defined as the ratio of total duration of rain rate that exceeds a particular threshold to the total time of rainfall in an average year. *i.e.*,

$$P_d = D / \overline{D}$$

where D = Total duration of a particular rain rate exceedance

$\overline{D}$ = Total time of rainfall per year

The nature of the curves is seen to follow the similar patterns as those in Figure 6. Once the value of P_d for a particular rain exceedance is known, a corrective measure in communication systems may be made. Similarly, the value of P_n will give an indication of

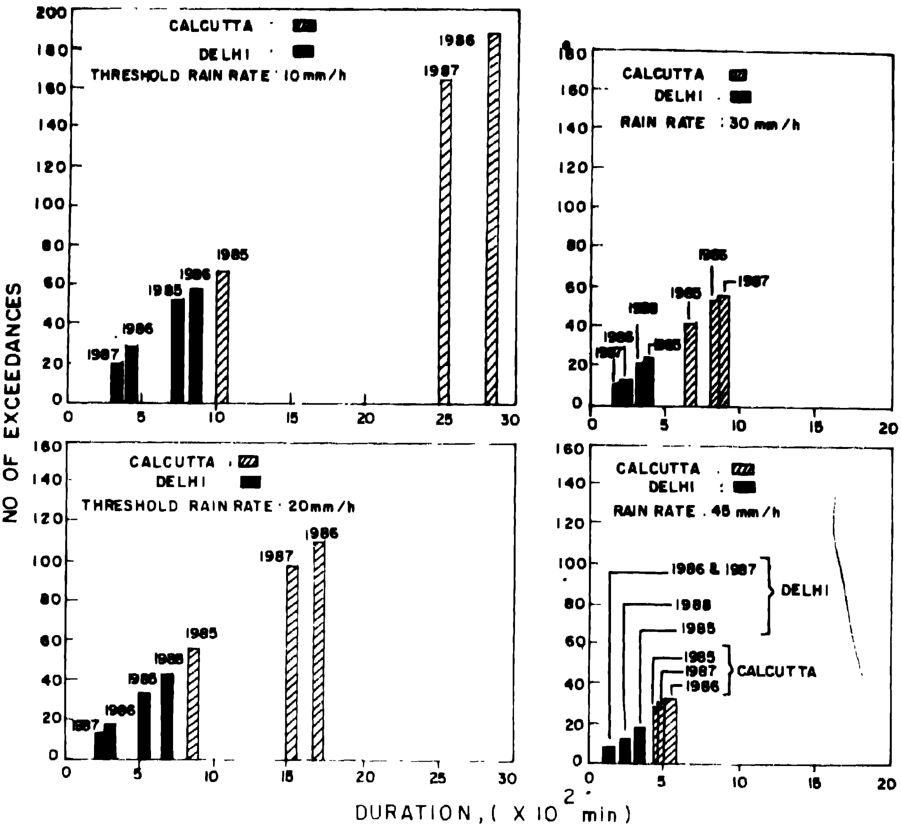

Figure 8. Histograms showing the degree of variability of duration as well as the number of exceedance for rain rate thresholds of 10, 20, 30 and 40 mm/h (the length upto left edge of histogram along X-axis represents the duration)

how often the exceedances will occur at a particular rain rate level (threshold) during the total rain fall time. An idea about both P_d and P_n can be used to the advantage of the system planning.

Figure 8 shows the degree of variability of duration as well as the number of exceedance for four rain rate thresholds for different years over Calcutta and Delhi. The number of exceedances and thereby the duration values stand always higher over Calcutta than over Delhi. The variation in these values for the above two stations reduces as one moves towards the higher thresholds. The cumulative average values of the same for different rain rate thresholds are depicted in Figure 9.

An estimate of the total average exceedance time per year of a particular threshold level may be made, in the present case, by multiplying the average number of exceedances ($\bar{N}$) by the integration time (T). This value divided by the number of minutes of an average year (525600) should give an estimate of the conventional outage probability (probability of

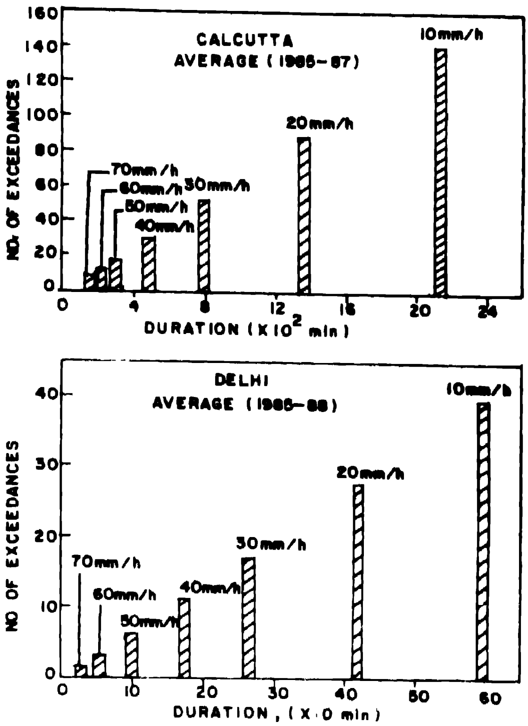

Figure 9. Histograms showing the cumulative average values of number of exceedances and duration for different rain rates (the length upto the left edge of each bar measures the duration along X axis)

total average exceedance per year) that a particular rain rate level is equalled or exceeded. Table 3 shows the estimated outage probability over Calcutta and Delhi on the basis of present calculation and analysis

Table 3 Outage probability (%) that a particular rain rate is equalled or exceeded over Calcutta and Delhi

(The values given within brackets are over Delhi and values given not within brackets are over Calcutta)

Rain rate (mm/h)	Av no of exceedance per yr ($\bar{N}$)	Total duration of rain rate that exceeds a threshold ($\bar{N}$ T), min	Outage probability (%) $\left[\frac{\bar{N}\ T \times 100}{525600}\right]$
10	140 (39 5)	2100 (592 5)	3.99×10^{-1} (1.13×10^{-1})
20	88 (27 5)	1320 (412 5)	2.51×10^{-1} (0.78×10^{-1})
30	51 (17 25)	765 (258 75)	1.15×10^{-1} (0.49×10^{-1})
40	30 (11)	450 (165)	0.86×10^{-1} (3.14×10^{-2})
50	18 (6)	270 (90)	0.51×10^{-1} (1.71×10^{-2})

Table 3 *(Cont'd)*

Rain rate (mm/h)	Av. no. of exceedance per yr. ($\bar{N}$)	Total duration of rain rate that exceeds a threshold ($\bar{N}$ T), min	Outage probability (%) $[\frac{\bar{N} . T \times 100}{525600}]$
60	12 (3)	180 (45)	3.42×10^{-2} (0.86×10^{-2})
70	8 (1.5)	120 (22.5)	2.28×10^{-2} (0.43×10^{-2})
80	5 (0.5)	75 (7.5)	1.43×10^{-2} (1.43×10^{-3})
90	0.66	9.90	1.88×10^{-3}
100	(0.25)	(3.75)	(0.71×10^{-3})
110	0.66	9.90	1.88×10^{-3}

It is shown in Table 3 that the outage probability is more for lower rain rates than for higher rain rates. Moreover, the outage probability for a particular rain rate is more over Calcutta as compared to that over Delhi. The probability value for 60 mm/h rain over Calcutta is found to be almost same for 40 mm/h rain over Delhi.

6. Conclusion

The present paper depicts rain related parameters and their interdependence. This study is important for the communication links and radar propagation, specially, for the link designers More such studies, covering wider rain data from different rain climatic regions of India, are required for sustainable link designing

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